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A pilot study of the color performance of recycling green building materials

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ABSTRACT

The concept of green building integrates a variety of strategies during the design, construction and operation of building projects. The use of green building materials represents one very crucial strategy during the design and construction of a building. Recycling green building materials refer to those building materials reproduced from other materials, namely, reclaim the waste or discarded materials to produce the building materials. In Taiwan, gypsum boards are widely used in the building industry as facing materials for walls and ceilings due to their very good mechanical and thermal properties, as well as fire endurance. The goal of this study is to develop a new recycling green building material which could reuse the daily waste materials, color changeable and give inspiration to improve the characters of green building materials. In this study, six waste materials in our daily lives were mixed with the allochroic powder and gypsum powder to create thermochromic face bricks. The experiment modules were Groups A, B, C, and D, and mixed with allochroic powders of different specifications. The findings showed that Group C had the most significant RGB variation. In terms of the G value of Group C, the variations of the six materials were wood chips 81.9% > , newspaper 78% > , concrete 75.6% > , fallen leaves 66.6% > , iron powder 59.2% > , and silt 50.9%. In conclusion, allochroic faced bricks can be applied to both interior and exterior walls of different types of buildings in the future, thus, the buildings have different colors at different temperatures and times, cater to the changeful effects of future architectural appearances. Regarding the landscape, building and interior designers can construct artistic creations of shell collages.

1. Introduction

The concept of green building integrates a variety of strategies during the design, construction and operation of building projects. The use of green building materials represents one very crucial strategy during the design and construction of a building. In particular, green building materials are composed of renewable, rather than nonrenewable resources. Also, green materials are environmentally responsible because impacts are considered over the life of the product [13–15].

On the other hand, recycling green building materials refer to those building materials reproduced from other materials, namely, reclaim the waste or discarded materials to produce the building materials. [5] indicated that recycling green building material products should completely conform to the three principles of Reuse, Recycle, and Reduce. Ray et al. (2010) proposed that recycling green building materials should be tested by proven laboratories authorized by the government, and passed products should be labeled to prove the products acceptable. According to Article 321 of the Building Design-Construction Chapter, of the Building Technical Regulations in the Building Act of Taiwan, the usage rate of green building materials should be 45% of the total area of interior decoration materials, and the usage rate of exterior green building materials should be higher than 10%.

Gypsum board is regarded to be green material according to Taiwan' related building regulations. In Taiwan, gypsum boards are widely used in the building industry as facing materials for walls and ceilings due to their very good mechanical and thermal properties, as well as fire endurance. The endothermic dehydration process that takes place at high temperatures is capable of slowing down the fire spread through gypsum board based systems [8,9].

In terms of the principle of color change, [12] indicated that the color of thermochromic dye could be changed by controlling the temperature, solvent polarity, and pH values, to rearrange the molecules. New Prismatic Enterprise (2012) proposed that the product color change principle was the basic principle of low temperature

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color development and high temperature colorless, within a temperature range of −15–70 [3]. Indicated that light stability resulted in differences in pigments. Therefore, in this study, the protective measures against light were strengthened, and anti-UV waterproof weather resistant coating material, light stabilizers, and antioxidants were used to protect the chromotropic dyes. [1] indicated that in terms of photochromism, the molecular structure was changed in solar and UV irradiation, thus, the wavelength changed, which changed the color. Meer (1876) reported that the chromotropic dye crystal turned purple from colorless in the sun, and the crystal restored to colorless when placed in the dark. Hirshbergd (1950) proposed light conversion, as some substances changed apparently when exposed to the sun. [11] found that different colors were derived from mixing the color lights in different wavelengths in the light rays, and all colors could be formed by mixing red, green, and blue color lights. [2] suggested that the three primary colors were an additive mixture, where the three color lights, plus each other, equals white; and minus each other equals black; the colors between black and white are gray scale colors. Two of the three primary colors of color lights can be mixed to generate three primary colors of pigments, i.e. R+G=Yellow, G+B=Cyan, and B+R=Magenta. The International Commission on Illumination (1931) selected the standard wavelengths of the basic stimulation RGB of color mixture as 700.0 nm, 546.1 nm, and 435.8 nm, respectively. [6] used a density meter to measure the RGB color density of the tested color lumps for different parameter settings, and conducted an objective evaluation. [10] indicated that the gray balance data were the base of color change in color image reproduction. [4] indicated that the gray balance color lump referred to the color lump of the α, b' coordinates closest to the various RGB origins. According to [2], the RGB values and HSL values of body surface colors could be measured using a color analyzer, which can be used to measure the surface coating colors of different cement mortar specimens. As mentioned above, RGB can be analyzed by various software and instruments.

The goal of this study is to develop a new recycling green building material which could reuse the daily waste materials and give inspiration to improve the characters of green building materials The research purposes of this study were to investigate (1) whether the waste materials in our daily lives can be recycled to mix with the allochroic powder and gypsum powder to create thermochromic face bricks; (2) whether the thermochromic characters of the allochroic powder will be affected or even destroyed because of the mix process; (3) the color change efficiency test for the self-made thermochromic face bricks.

The research results can reduce the waste materials in our daily lives and give inspiration to improve the characters of green building materials.

2. Materials and methods

2.1. Research materials

This study was carried out in an interior laboratory of Mingdao University in Taiwan. In this study, six waste materials in our daily lives were mixed with the allochroic powder and gypsum powder to create thermochromic face bricks. Initially, six waste materials (i.e. iron powder, newspaper, fallen leaves, silt, wood chips, and cement blocks) were made into small particles. Iron powder, silt and wood chips were small particles already; therefore, they did not need further treatment. Newspaper, fallen leaves were broken to pieces by using a small bruising mill. Cement blocks were broken to pieces by using a hammer.

Secondly, the above small particles were further mixed with allochroic powder and gypsum powder to create thermochromic face bricks. The face brick made of waste materials was 1.5 cm thick, composed of a 1.19 cm thick bottom layer, a 0.3 cm thick allochroic layer, and a 0.01 cm thick surface protection coating material, from bottom to top.

The size of face bricks was unified at 5 cm × 5 cm × 1.5 cm (LxWxH). Referring to [7], the gypsum board should be fireproof and soundproof, thus, this study mixed anhydrite with allochroic powder and different kinds of waste to make face bricks. The die was a $7 \times 7 \times 2$(cm) square hollow plastic die. The production steps of the face bricks are: (1) bottom layer: various wastes are made into small particles less than 0.3 cm, which are mixed with gypsum and water; the material ratios are 15 g gypsum (25%), 60% waste, 15% water, and 0.5 ml antioxidant and stabilizer, respectively, which are stirred for about 1 min and poured in the die, about 1.19 cm thick. According to the green building policy [5] proposed Ministry of Interior (Taiwan, R.O.C.) that the waste ratio of recycling green building materials should be higher than 50%. In order to in comply with the above policy, a waste ratio of 60% was adopted in this study. In addition, other material ratios are selected to be 25% for gypsum and 15% for water after several times of trials; (2) allochroic layer: 1.5–2 g allochroic powder (8%), 60% gypsum, and 32% water, are mixed to make the allochroic layer; the allochroic layer is 0.3 cm thick, and dried for one day; 3) surface protection coating material: 0.01 cm weather resistant surface protection coating material is painted after the experiment. The experiment modules were divided into Groups A, B, C, and D according to the allochroic powder mix ratio, and each group had the same six materials. Table 1 shows the addition of allochroic powder at different temperatures. Group A used the contrast colors of blue and orange paint (0.5 g model: acryliuqe301 poster paint) mixed with allochroic powder (blue 25 °C, 2 g). Group B contained two kinds of allochroic powders at different temperatures (yellow 31 − 1 g, blue 25 − 1 g). Group C contained three kinds of allochroic powders at different temperatures (yellow 31 − 0.5 g, blue 25 °C − 0.5 g, red 20 °C − 0.5 g). Group D contained three kinds of allochroic powders at different temperatures (yellow 40 °C − 0.5 g, blue 31 °C − 0.5 g, red 20 °C − 0.5 g).

The face bricks of the six materials of groups A, B, C, and D were produced according to the aforesaid method. The photos of the finished face bricks are shown in Table 2. In terms of experimental apparatuses, color analyzer TECPEL Tech-Link-TES 135 was used for RGB analysis. A digital thermometer was used to measure face brick temperature, and the temperature measurement range was −10 °C to +70 °C. Ice cubes were used for material cooling. The size was about 3 cm × 3 cm × 3 cm. The heating equipment was a SAMPO 10″ desktop electric radiator HX-FA10F, and the digital camera was Sony DSC-W620, with 14.1 mega pixel. Soil moisture and pH meter DM-15 was used to prepare the face brick moisture, with a measuring range of: 1–8.

2.2. Research method

2.2.1. Color change efficiency test for the green building materials of the various groups

The experimental period was from June 2012 to March 2013. Ice cubes and an electric radiator were used for cooling and

Table 1.
Allochroic powders at different temperatures of groups A, B, C, and D.

	A	B	C	D
Yellow		31 °C (1 g)	31 °C (0.5 g)	40 °C (0.5 g)
Blue	25 °C (2 g)	25 °C (1 g)	25 °C (0.5 g)	31 °C (0.5 g)
Red			20 °C (0.5 g)	20 °C (0.5 g)

Note: yellow (R255, G255, B0), blue (R0, G0, B255), red (R255, G0, B0) a, e.g. yellow allochroic powder 31, the allochroic powder turns yellow when the temperature is 31, is colorless at high temperatures, and chromogenic at low temperatures.

heating experiments, as shown in Figs. 1 and 2. The test temperature range was set according to Taiwan's air temperatures in four seasons. The simulated winter temperature range for the cooling experiment was 30–15 °C, and the interior was cooled by air conditioning and ice cubes. The measured face brick was fixed with insulating tape on glass, which was maintained at a distance from the ice cubes. When the temperature dropped, the color analyzer adhered to the face brick surface, three measurements were rapidly recorded. The average value of the three measurements was taken, and the temperature and RGB values were recorded. The heating experiment simulated summer, with a temperature range of 30–40 °C. The face brick was affixed to the wall, and temperature was controlled by the distance between the heater and face brick. Each time the temperature rise by 1 °C, the color analyzer was placed close to the face brick to take three rapid measurements, and temperature and RGB values were recorded. Groups A, B, C, and D had the same experimental procedures, and only Group A used the cooling experiment because Group A only had blue 25 °C allochroic powder.

Table 2.
Photos of the six materials of groups A, B, C, and D.

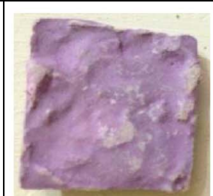
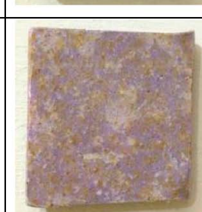
Materials	A	B	C	D
Wood chips				
Newspaper				
Fallen leaves				
Concrete				
Silt				
Iron powder				

Fig. 1. Cooling experiment.

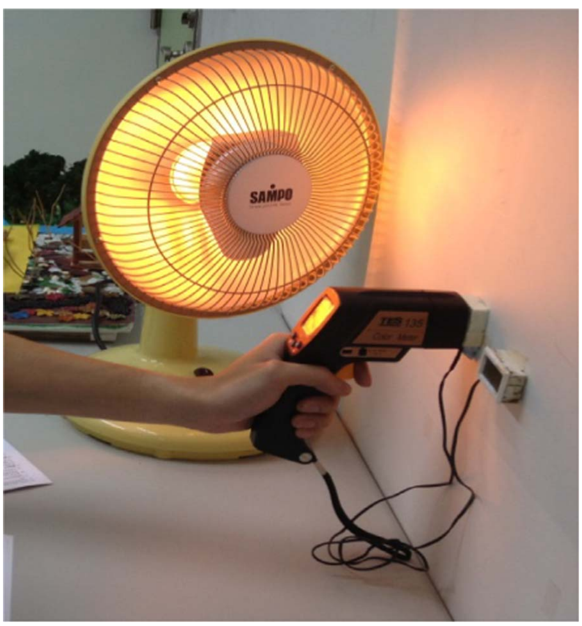


Fig. 2. Heating experiment.

2.2.2. *Color change efficiency of recycled newspaper modules among the four groups*

Newspaper materials with optimal performance were selected from groups A, B, C, and D to observe the RGB variation (maximum value is 255) for cross comparison and analysis. The findings showed the applicable environment to the allochroic face bricks of the four groups in the future, and the color change efficiency of the various groups.

3. Results and discussion

3.1. *Mixing process*

The results of the 4 groups showed that the waste materials in our daily lives can be applied to mix with the allochroic powder and gypsum powder to create thermochromic face bricks. The result is very exciting as it could not only reduce the amount of waste in Taiwan, but also give good inspiration to the recycling green building materials.

3.2. *Thermochromic characters and appearance of the face bricks*

The appearances of face bricks made of the six waste materials, allochroic powder and gypsum powder were shown in Table 2. One thing we are very concerned is whether the thermochromic characters of the allochroic powder would be affected or even destroyed by the mixing process? The answer is NO. This is such good news and this implies that the allochroic powder has kept its thermochromic characters during the mixing process with the six waste materials and gypsum powder.

Table 2 also showed the appearance of the face bricks in room temperature. If we look at the first row (i.e. Wood chips), we can see that the colors of groups A, B, C and D are roughly pink, slate-gray, slate-gray, and dark-pink, respectively. The second row (i.e. Newspaper) performed very similar colors with the first row. The third row (i.e. Fallen leaves) performed also similar colors with the first and the second rows but the color change of the third row seems a little larger. In particular, one thing worth noting is that groups B & C seems to have closer colors.

3.3. *Color change efficiency test for green building materials of the various groups*

3.3.1. *Group A*

According to the RGB variations of the six wastes of Group A at 15–25 °C, wood chips had the maximum variation R value in Group A at 15–25 °C, which is 45.8%. Silt had the minimum variation of 27.1%. The difference between R values of wood chips and silt at 25 °C was 103. Wood chips had the maximum variation of G value, which is 32.9%. Silt had the minimum variation of 11.7%. The difference between the G values of wood chips and silt at 25 °C was 65. Concrete had the maximum variation of B value, which is 65.8%. Iron powder had the minimum variation. The difference between B values of concrete and iron powder at 25 °C was 106. The RGB values of the six materials at 20–25 °C in Group A had significant variation. The R value of wood chips at 20–25 °C was increased by 110, as the blue 25 °C allochroic powder was effective, and the maximum variation occurred at 24–25 °C, which was increased by 60. The minimum variation of RGB values of the six materials at 15–25 °C was 11.7% (Fig. 3).

3.3.2. *Group B*

The RGB variations of the six materials of Group B at 15–40 °C are as shown in Fig. 4. Wood chips had the maximum variation of R value at 15–40 °C in Group B, which is 60.3%. Silt had the minimum variation of 29.8%. The difference between R values of wood chips and silt at 40 °C was 77. Concrete had the maximum variation of G value, which is 41.5%. Iron powder had the minimum variation of 18.8%. The difference between G values of concrete and iron powder at 40 °C was 54. Newspaper had the maximum variation of B value, which is 49.8%. Fallen leaves had the minimum variation of 20%. The difference between B values of newspaper and fallen leaves at 40 °C was 59. The RGB values of the six materials at 15–25 °C were in a proportional relationship. For example, the R value of wood chips at 15–25 °C increased by 144, the 31 °C yellow allochroic powder began to react at 25–30 °C. As yellow chroma was higher, the RG values were unlikely to change; whereas, the B value decreased. The B value of wood chips at 25–30 °C decreased by 70. The overall RGB values of the six materials at 40 °C were relatively high, indicating that the object is colorless. The RG values changed slightly at 31–40 °C. The R value of wood chips increased by only 5.1%, and the G value increased by only 2.7%, indicating that the color change effect of face bricks at high temperature is worse. Group B had the maximum variation of RGB values at 15–40 °C, the R value of wood chips was 60.3%; while iron powder had the minimum G value of 18.8%.

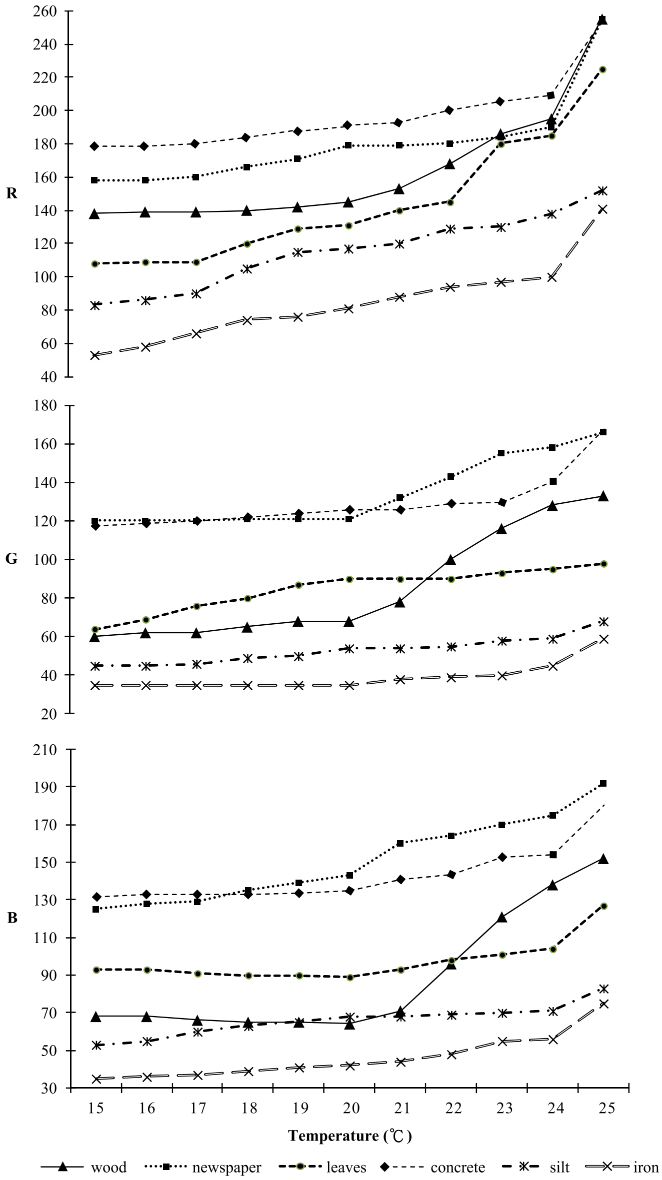


Fig. 3. RGB values of Group A.

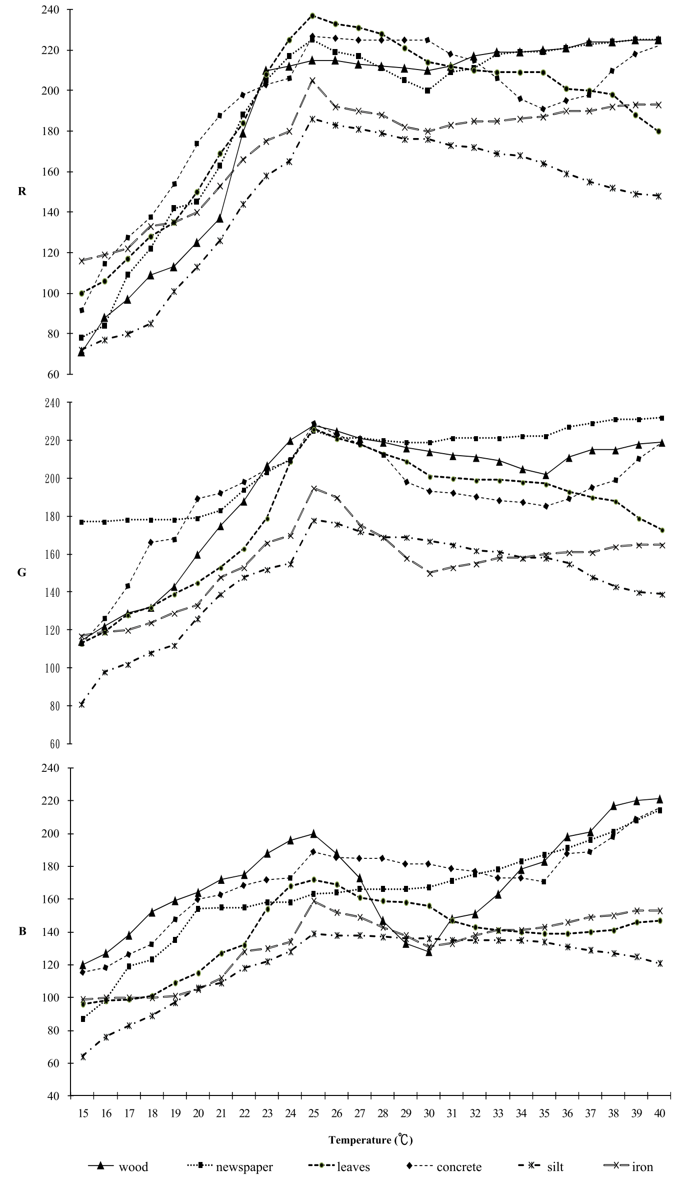


Fig. 4. RGB values of Group B.

3.3.3. Group C

The RGB variations of the six materials of Group C at 15–40 °C are as shown in Fig. 5. Concrete had the maximum variation of R value in Group C, which is 74.9%. Silt had the minimum variation of 50.9%. The difference between R values of concrete and silt at 40 °C was 54. Wood chips had the maximum variation of G value, which is 81.9%. Silt had the minimum variation of 50.9%. The difference between G values of wood chips and silt at 40 °C was 78. Newspaper had the maximum variation of B value, which is 75.2%. Silt had the minimum variation of 49.8%. The difference between the B values of newspaper and silt at 40 °C was 74. The overall RGB values at 15–25 °C were lower than 100 or 50. The G values of the six materials at 15–18 °C were lower than 50. As the three kinds of allochroic powder began to react, the color was darkened, and the overall data decreased. The differences among the RGB values of the six materials increased at 25 °C. The R value of wood chips at 40 °C was different from silt by 68. The G value of wood chips with a maximum variation of RGB value was 81.9%, and the minimum B value of silt was 49.8%.

3.3.4. Group D

The RGB variations of the six kinds of waste in Group D at 15–40 °C are as shown in Fig. 6. Concrete had the maximum variation R value at 15–40 °C in Group D, which is 69.8%. Silt had the minimum variation of 39.2%. The difference between the R values of concrete and silt at 40 °C was 63. Wood chips had the maximum variation of G value, which is 72.5%. Silt had the minimum variation of 43.9%. The difference between the G values of wood chips and silt at 40 °C was 66. Newspaper had the maximum variation of B value, which is 62.3%. Iron powder had the minimum variation of 40%. The difference between the B values of newspaper and iron powder at 40 °C was 66.

The overall RGB values of the six materials of Group D had a 15–40 °C increase. The R value of wood chips at 15–40 °C was increased by 163. There were apparent differences in the RGB values of the six materials until the temperature was 30–40 °C. The difference between the R values of wood chips and iron powder at 40 °C was 33.3%. Wood chips had the maximum variation of G value among the RGB of the six materials of Group D at 15–40 °C, which is 72.5%. Silt had the minimum variation of R value, which is 39.2%.

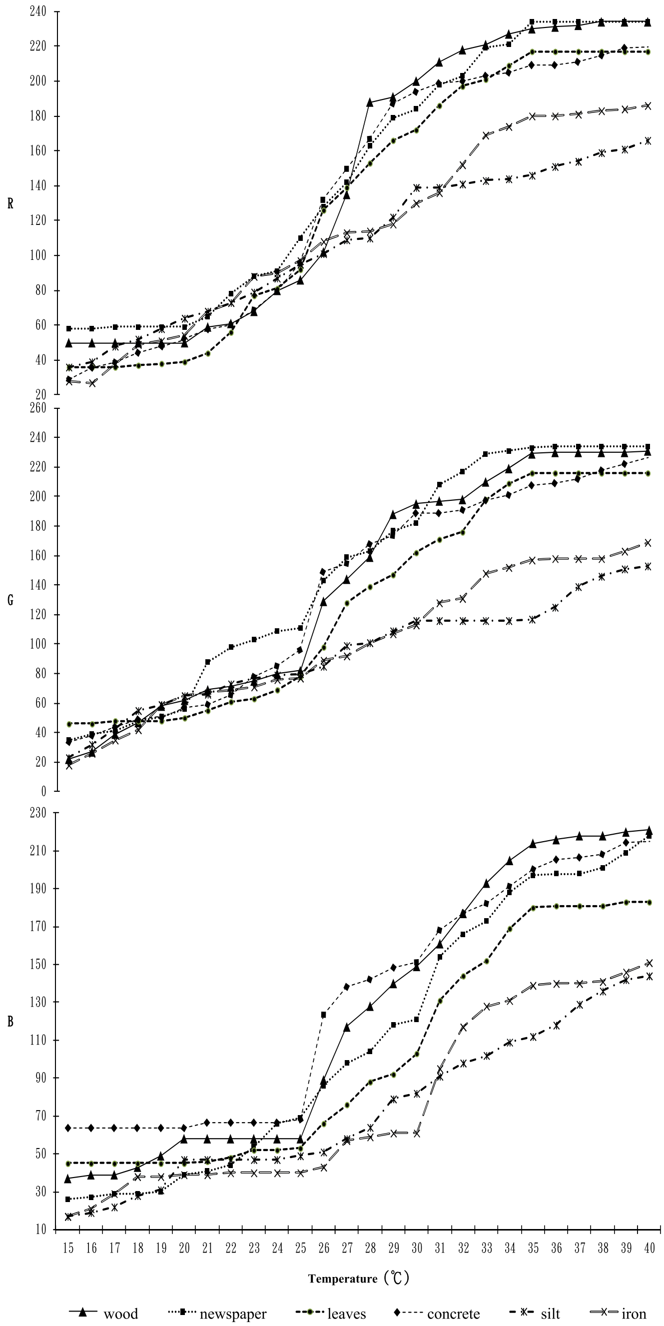


Fig. 5. RGB values of Group C.

3.4. Color change efficiency of recycled newspaper modules among the four groups

3.4.1. R value

It is known that newspaper is a daily waste. If newspaper can be renewed by this method, it will greatly reduce the daily amount of waste in Taiwan. The newspaper module of groups A, B, C, and D was selected for analysis and comparison of RGB. Group A had the maximum R value at 15 °C. The difference between Groups C and D was 39.21%. As Group A had only one allochroic powder; whereas, Groups C and D had three kinds of allochroic powder, a low value at low temperature occurred. Group B at 15 °C was also higher than Groups C and D by 7%, as it had only two kinds of allochroic powder, it was higher than Groups C and D. The R value of Group A at 25 °C had reached 100%, which was related to the additional normal orange paint in Group A, and the values of Groups C and D at 15–20 °C were lower than 15.2%. As they had three kinds of allochroic powder, the data were lower at low temperatures. The difference between Groups C and D increased at 25 °C, and the maximum gap was 30.9%. The difference between Group B at 31 °C and Group C decreased, and was only 6.6%, as they had additional 31 °C yellow allochroic powder (Fig. 7).

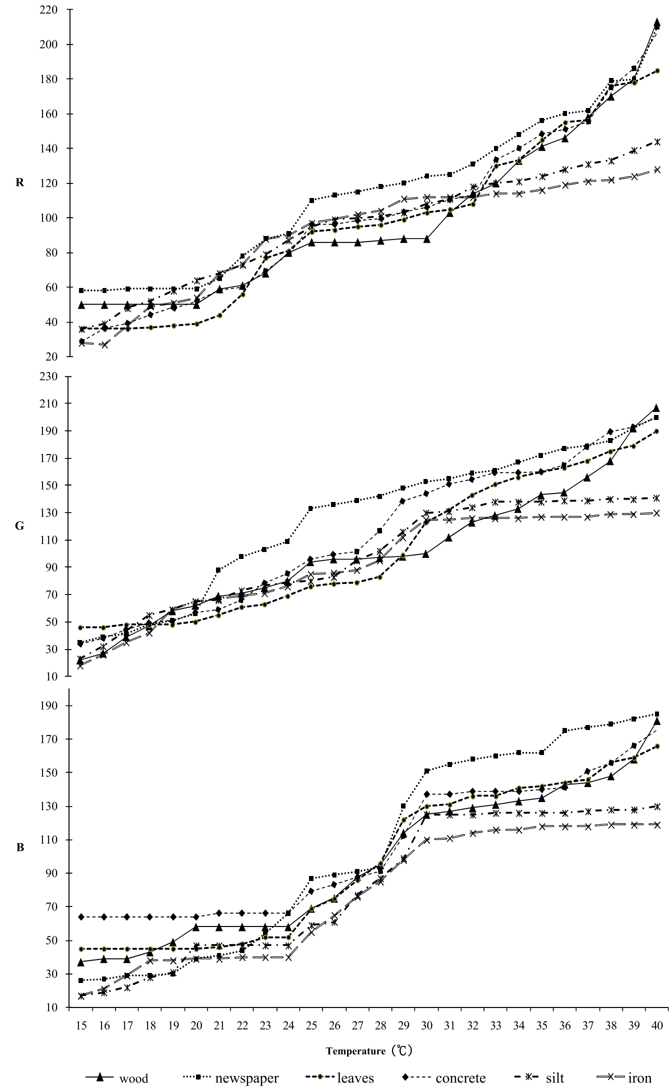


Fig. 6. RGB values of Group D.

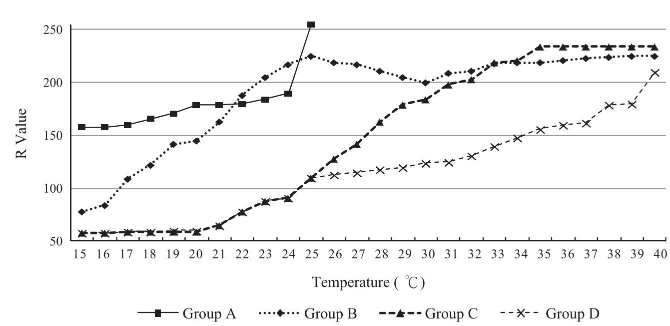


Fig. 7. R values of newspaper of Groups A, B, C, and D.

3.4.2. G value

Group B had the maximum G value at 15 °C, different from Groups C and D, with the minimum value by 55.6%. Group A had

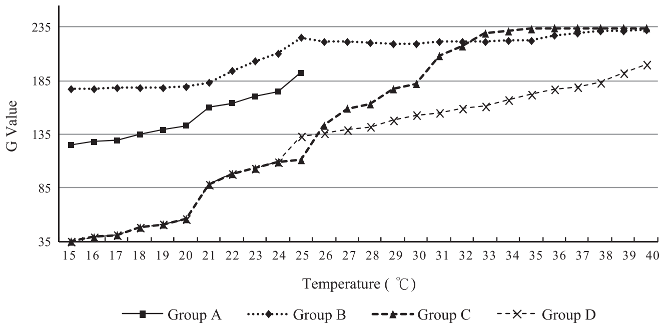


Fig. 8. Differences among G values for newspaper of Groups A, B, C, and D.

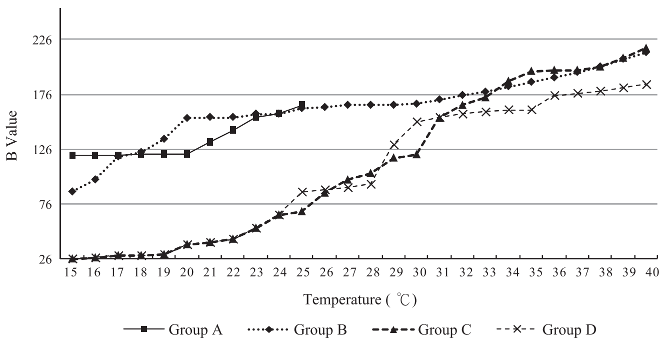


Fig. 9. Differences among B values of newspaper of Groups A, B, C, and D.

only one additional allochroic powder; however, its data were less than Group B by 20.3%, which may be because Group A had additional normal orange paint. Group A had additional blue 25 °C allochroic powder. According to the pigment mixing principle, the mixture of blue and orange is modena. Therefore, Group A at 25 °C was 12.9% different from Group B. Group C was close to Group D at 15–24 °C, which is due to the addition of allochroic powder. The overall values of Group B at 15–40 °C were higher than 69.4%, suggesting that the overall color of Group B is light (Fig. 8).

3.4.3. B value

Group A had higher B value at 15 °C, which is different from Group B by 12.9%; and from Groups C and D by as high as 36.8%. Groups C and D at 15–24 °C had the same value. The increase in Group B at 20–40 °C was slowed, and was only 23.5%. The increase in Group D at 30–40 °C was only 13.3%. The difference between Groups C and D at 40 °C was 12.9% (Fig. 9).

4. Conclusions

The study results showed that the waste materials in our daily lives can be applied to mix with the allochroic powder and gypsum powder to create thermochromic face bricks. Besides, the thermochromic characters of the allochroic powder will not be affected or even destroyed during the mix process with waste materials.

The six kinds of waste were mixed with gypsum, allochroic powder, and protective paint, the face bricks actually changed at the various temperatures, and according to the temperature type of allochroic powder. For example, the R value of the wood chips of Group A at 25 °C was 255; the G value was 152; the B value was 133. The R value was 138; G value was 68; and B value was 60 at 15 °C, suggest that they were apparently changed. The experimental results showed that Group C has the most significant variation of RGB. The variations of the G values of the six materials in Group C are wood chips 81.9% >, newspaper 78% >, concrete 75.6% >, fallen leaves 66.6% >, iron powder 59.2% >, and silt 50.9%.

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